ARMY RESEARCH LABORATORY

Performance Metrics for Acoustic Classification of Weapons Fire

by Geoffrey H. Goldman, Ronald M. Holben, and Guy L. Williams

ARL-TN-0498 **September 2012**

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
September 2012	Final	

4. TITLE AND SUBTITLE
Performance Metrics for Acoustic Classification of Weapons Fire

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Geoffrey H. Goldman, Ronald M. Holben, and Guy L. Williams

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: RDRL-SES-P
2800 Powder Mill Road
Adelphi, MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TN-0498

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
U.S. Army Research Laboratory (ARL) personnel developed performance metrics for classifying acoustic signals from weapons fire. The metrics were written to differentiate between broad categories of events, rather than to identify specific weapon types. They were generated to discriminate between acoustic events that occurred at the point of origin (POO) versus acoustic events that occurred at the point of impact (POI), between direct- and indirect-fire weapons, and between small arms, recoilless weapons, mortars, and artillery for a defined scenario. This report provides metrics for scientists and engineers to evaluate their algorithms. They do not represent a requirement for any system under development.

15. SUBJECT TERMS
Acoustic classifier weapons fire direct indirect POO

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Geoffrey H. Goldman
Unclassified	Unclassified	Unclassified	UU	14	19b. TELEPHONE NUMBER (*Include area code*) (301) 394-0882

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Acknowledgments

We would like to thank Sue Toth for supporting this work and Kirk Alberts and Duong Tran-Luu for their helpful discussions on classifiers.

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1. Introduction

Soldiers in theater taking fire from hostile forces often have limited situational awareness even though they have access to data from multiple sensors. Processing the data into actionable information is often a difficult task. One aspect of this task is determining what information should be reported. Based upon subjective opinions, this report describes what information should be reported to a Soldier taking fire in a Forward Operating Base (FOB), Combat Outpost (COP), or similar area and how to quantify its accuracy. While the metrics were developed for acoustic sensors, they can also be applied other sensor modalities.

Acoustic sensors are good at finding the direction and location of loud acoustic sources, and fielded systems in theater currently report this information (*1*). Requirements for detection and false alarm rates have been developed for several acoustic systems (*2, 3*). However, a literature search did not find requirements or guidelines for acoustic classification of weapons systems. Accurately classifying the acoustic signature of weapons fire is a difficult problem due to atmospheric attenuation, dispersion, multipath, wind, and ambient noise. Although many algorithms have been developed and tested, the evaluation criteria remain ill defined. The criteria are subjective and depend upon the scenario of interest. However, by developing evaluation criteria, we provide insight into what information is important and provide a metric for scientists and engineers to use to evaluate their algorithms.

This report defines evaluation criteria for three classification/discrimination problems based upon the judgments of two military analysts with experience in theater and an acoustic research scientist. The criteria are based upon scenarios where the weapons are fired without suppressors from an open area and the rounds are landing in an open area. The classifier receives data from an acoustic detection and/or bearing estimation system. The system could consist of a single microphone, an array of microphones, or several arrays of microphones. The classification algorithm can be based upon the combined results from multiple acoustic sensors.

2. Classifier

Classifier performance metrics were generated to distinguish between three broad categories of events, rather than to identify specific weapon types, for three problems. First, the classifier should be able to determine whether an acoustic event occurred at the point of origin (POO) or at the point of impact (POI) for large-caliber mortars, rockets, and artillery. For events occurring at the POO, the classifier should be able to discriminate between direct-fire and indirect-fire weapons. Lastly, the classifier should be able to discriminate between acoustic events generated by small arms, recoilless weapons, mortars, and artillery. There is interest in further classifying

each weapons system category, but it is not addressed in this report. The classifier should only output results that meet the specified performance criteria. Partial output is acceptable. For example, classifying an event as the launch of a direct-fire weapon of unknown type is acceptable.

The metrics are described in the form of a confusion matrix with probabilities reported instead of numbers. They are for a specific range where the acoustic event occurred relative to the closest point on the perimeter of the FOB or mobile position. Additionally, the performance of the classifier at smaller ranges should be equal to or greater than the performance at the specified range. Median ambient noise levels at the sensors site near or at the FOB are assumed to be 60 dBA or less without filtering and will typically generate a low false alarm detection rate. However, occasional large transient acoustic signals generated by car doors slamming, helicopters flying by, hammering, yelling, and other sources of acoustic signals will potentially trigger the detection algorithm. These events are considered to be in the classifier category of noise.

The performance criteria for discriminating between POO and POI for large weapon systems and noise are shown in table 1. Large-caliber weapon systems include mortars, any tube artillery, and rocket artillery. The specified range for POO and POI is 2500 and 300 m, respectively. The table indicates that the probability of correctly classifying the launch or impact of a weapon is 75% or greater and the probability of incorrectly classifying noise as a launch or impact of weapon fires is 25% or less.

Table 1. Probability for discriminating between launch and impact.

		Predicted Weapon Event		
		Launch	**Impact**	**Noise**
Actual Weapon Event	Launch	>75 %	<25 %	<25 %
	Impact	<25 %	>75 %	<25 %
	Noise	<30 %	<30%	>70%

The performance metrics for discriminating between the launch of direct-fire weapons, such as a small arms and recoilless rifle; indirect-fire weapons, such as mortars and artillery; and noise are shown in table 2. The specified ranges are 500 and 1500 m for direct- and indirect-fire weapons, respectively. The table indicates that the probability of correctly classifying of a direct-fire weapon is 75% or greater and the probability of incorrectly classifying a direct-fire weapon as an indirect-fire weapon is 25% or less.

Table 2. Probability for discriminating between the launch of direct- and indirect-fire weapons.

		Predicted Weapon Type		
		Direct	**Indirect**	**Noise**
Actual Weapon Type	Direct	>75 %	<10 %	<25%
	Indirect	<10 %	>75 %	<25%
	Noise	<30%	<30%	>70%

The performance metrics to discriminate between the launch of small arms, recoilless weapons, mortars, and artillery are shown in table 3. The specified ranges are 300, 500, 1500, and 2500 m, respectively. The small arms category includes pistols, carbines, assault rifles, under-barrel grenade launchers, light machine guns, general purpose machine guns, heavy machine guns (calibers up to 20 mm), and automatic grenade launchers. The recoilless weapons category includes shoulder-fired rockets such as anti-tank grenade launchers and anti-tank guided missiles. The table indicates that the probability of direct-fire weapons such as small arms being classified as indirect-fire weapons such as mortars or artillery should be very small: 5–10%.

Table 3. Probability for the classification of the launch of different weapon types.

		Small Arms	**Recoilless**	**Mortar**	**Artillery**	**Noise**
Actual Weapon type	Small arms	>75 %	<25 %	<10 %	<5 %	<25 %
	Recoilless	<10 %	>75 %	<25 %	<5 %	<25 %
	Mortar	<10 %	<20%	>75 %	<25 %	<25 %
	Artillery	< 10 %	<10 %	<25 %	>75 %	<25 %
	Noise	<10 %	<10 %	<10 %	<10 %	>70%

3. Conclusion

Performance metrics for classification and discrimination of acoustic signal from weapons fire were developed to help support scientist and engineers evaluate their algorithms. We developed performance metrics to discriminate between broad categories of events including a noise category rather than specific weapon systems. It is anticipated that one of the biggest challenges for meeting the performance criteria is to not classify noise events such as car doors slamming as weapon systems fire. Failure to meet this criterion may result in classification results in future systems being ignored or future systems being turned off. These metrics do not represent performance criteria for any system under development and are not associated with any Operational Needs Statement (ONS) from any theater of operations.

4. References

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